

# DER-CAM

## DOE FY15 2<sup>nd</sup> Quarterly Review

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**DER-CAM** DECISION SUPPORT TOOL FOR  
DECENTRALIZED ENERGY SYSTEMS  
ANALYTICS | PLANNING | OPERATIONS

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Partners: Massachusetts Institute of Technology (MIT), EPRI, Metropolitan  
Washington Council of Governments, Brookhaven National Laboratory, Fort  
Hunter Liggett, TriTechnic, Microgrid Labs Inc., MIT Lincoln Laboratory,  
University of New Mexico, Public Service New Mexico, Universidad Pontificia  
Comillas – IIT, Xcogen Energy LLC, CSIRO, NEC



**U.S. DEPARTMENT OF  
ENERGY**



# Overview Collaborations with BNL/COG/EPRI and Technical Progress

	planned	status
BNL	provide DER-CAM training to BNL, including formatting , inputting data, running scenarios, analyzing and interpreting results, and understanding the technologies in DER-CAM	completed
	LBNL provides advanced training to BNL staff on DER-CAM code	completed
	LBNL shall develop a user manual for the DER-CAM	completed
COG	support COG on engineering / economic analysis of microgrid development options for the St. Elizabeth's campus in DC	formed collaboration with EPRI and support COG, ongoing
	support and guide efforts to collect and enter data, design of analysis and sensitivities, use of the model	provided data templates to ease the data collection, training videos
EPRI	transfer DER-CAM to EPRI to support utilities, governments, etc.	very successful (e.g. NYPrize)
	form collaboration with EPRI and improve DER-CAM based on user feedback	very successful (e.g. improved result section)
Techn. Progr.	technology transfer	exceeding expectations
	enable DER-CAM with “green field” vs. “brown field” optimization	completed
	enable DER-CAM with unbundled transmission and distribution tariffs to consider changed tariff structures	ongoing
	take lead on interface design (web-based)	very successful
	start with power flow capabilities	ongoing and accelerated progress

# Major DER-CAM Accomplishments #1

## Outreach and TechTransfer work in the 2<sup>nd</sup> quarter

**delivered as planned, with accelerated outreach to industrial and commercial users; DER-CAM classes and feedback from DER-CAM users**

- transferred DER-CAM to EPRI
  - EPRI uses DER-CAM for microgrid design with its utility partners
  - NYPrize proposal with communities and utilities
  - EPRI uses DER-CAM to support the Metropolitan Washington Council of Governments (COG) for the St. Elisabeth's Hospital complex
- trained BNL staff on DER-CAM for use with communities and utilities in NY state, full week DER-CAM class
- adopted by engineering firms as General Electric, the Burns Group
- IEEE 2030.7 WG on microgrid controller standards

## Technical work performed in 2<sup>nd</sup> quarter of FY15

**completed as planned, with accelerated progress**

- released next version of web-based interface microgrid design tool
- accelerated progress on microgrid topology, power flow capabilities
- additional DER-CAM features (load data processing, results navigation, graphical reports), collaboration with EPRI and member utilities, EPRI provided very helpful input for improving the DER-CAM interface
- advanced CHP module and data, 60% completed

## Major DER-CAM Accomplishments #2

- General Electric (GE) uses DER-CAM for microgrid projects
- Burns Engineering and Construction is using DER-CAM for the Philadelphia Navy Yard microgrid project and receives ongoing DER-CAM support and training
- Industry Advisory Group: GE, EPRI, Microgrid Labs, BNL, and multiple users are providing feedback on DER-CAM
- DER-CAM classes – well subscribed
  - the May 4<sup>th</sup> class was oversubscribed (26 users) and follow up sessions have been provided on May 6<sup>th</sup>, May 8<sup>th</sup>, and May 10<sup>th</sup>
  - participants from Schneider Electric, the Burns Group, Duke Energy, ConEdison, Google, Clean Coalition

## Major DER-CAM Accomplishments #3

- ARUP, a facility engineering firm is evaluating DER-CAM for urban development projects
- completed a full conceptual microgrid design with DER-CAM for Fort Hunter Liggett
- customized DER-CAM versions developed for advanced users are offered
- completed a manual, 50 pages, includes a use case, which is available at [https://building-microgrid.lbl.gov/sites/all/files/DER-CAM User Manual v1 Rev2.pdf](https://building-microgrid.lbl.gov/sites/all/files/DER-CAM_User_Manual_v1_Rev2.pdf)

# Major DER-CAM Accomplishments #4

The image shows a screenshot of the DER-CAM User Manual. The main window displays the title page, which includes the text "DER-CAM User Manual", "Full DER Web Optimization Service: a project partly financed by the U.S. Department of Energy", and "DER-CAM Version 4.4.1.3". Below this, it says "Interface Version 1.4.1.0" and "Copyright © LBNL 2008-2015". The Lawrence Berkeley National Laboratory (LBNL) logo is also present.

A smaller window in the foreground shows the "Building retrofit settings" section, which discusses the impact of passive building improvements on energy loads and heat losses. It also mentions financial incentives and the California Self-Generation Incentive Program.

Another window in the foreground shows a table titled "Forced Investment Parameters". The table has four columns: "F1", "ForcedInvest", "ForcedInvestCapacity", and "Existing". The rows list various energy storage and generation technologies, with "PV" highlighted in blue.

F1	ForcedInvest	ForcedInvestCapacity	Existing
1 ElectricStorage	0	0	0
2 HeatStorage	1	0	0
3 ColdStorage	1	0	0
4 FlowBatteryEnergy	1	0	0
5 FlowBatteryPower	1	0	0
6 AbsChiller	1	0	0
7 AbsRefrigeration	1	0	0
8 PV	0	100	1
9 SolarThermal	1	0	0
10 EVs1	1	0	0

# DER-CAM Partners

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ANALYTICS | PLANNING | OPERATIONS



## Our Partners





# DER-CAM

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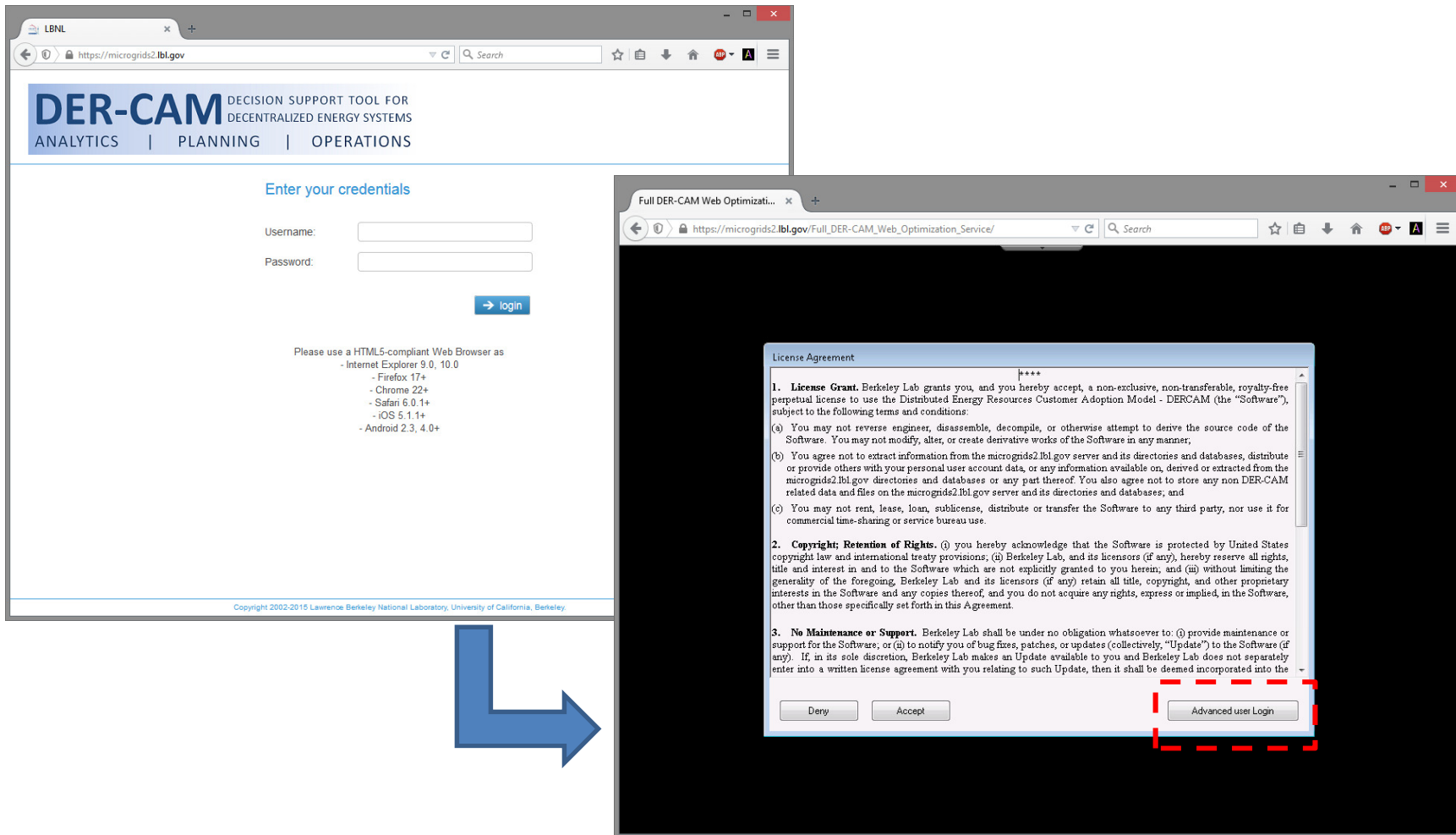
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## *Excerpt of Technical Work Performed in 2<sup>nd</sup> quarter of FY15:*

- *web-based interface design and expanded DER-CAM's role as leading microgrid design tool*
- *improved user Interface (load data processing, results navigation, graphical reports)*



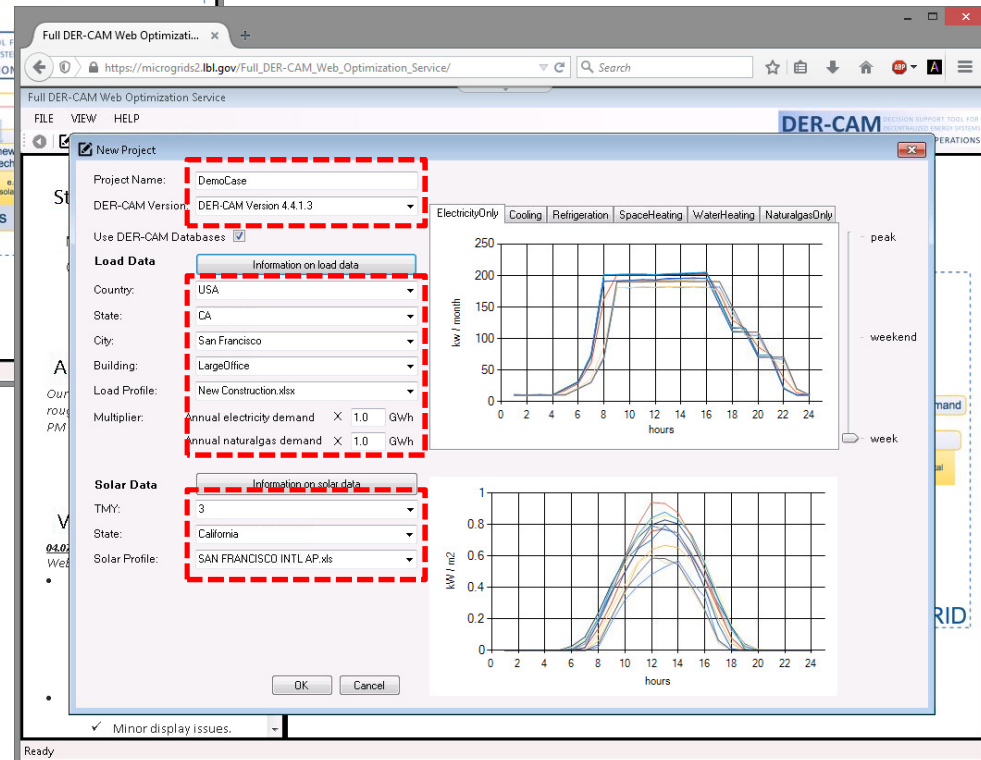
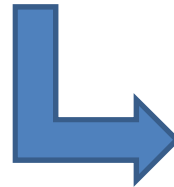
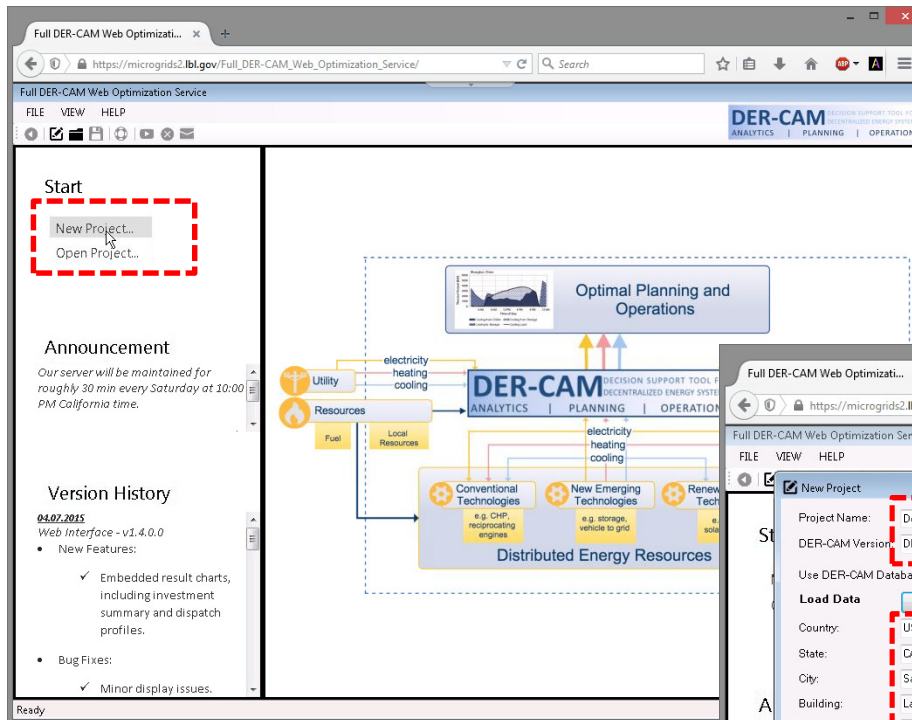
# Login Screen



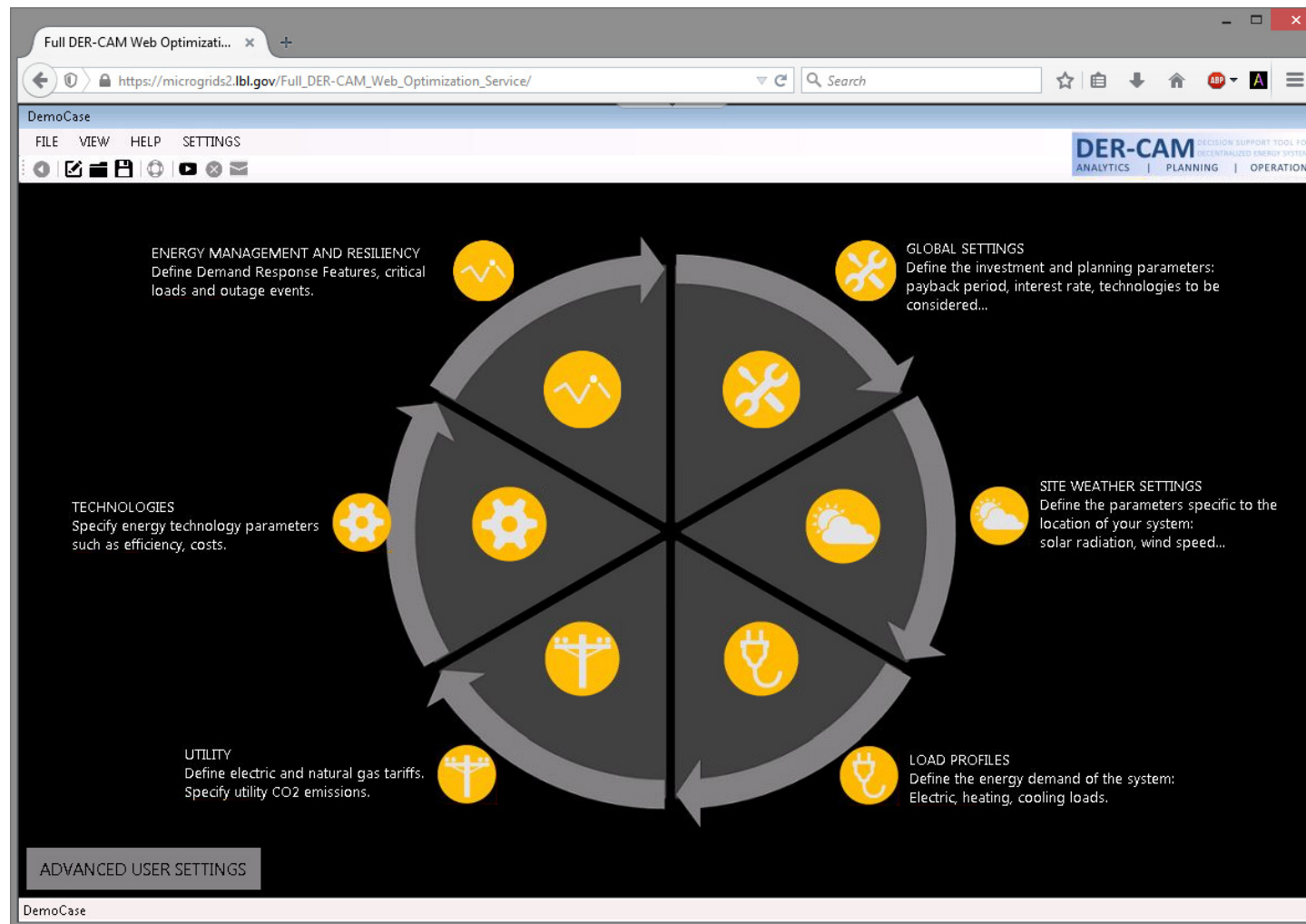
advanced user login allows access to customized versions

# New Project

## Small Renewable Microgrid



# Model Overview



# Model Overview: Closer Look at the Utility Sub-Menu

The screenshot displays the DER-CAM web application interface. The left sidebar (labeled 1) shows the 'Parameters' menu with 'Utility' expanded, listing options like 'Global Settings', 'Electricity Rates', and 'Fuel Rates'. The main area (labeled 2) shows the 'Monthly Demand Rates' table with columns for month, F1, coincident, noncoincident, onpeak, and midpeak. The right panel (labeled 3) displays the 'Monthly Demand Rates - Help' text, explaining the unit and control periods.

	F1	coincident	noncoincident	onpeak	midpeak
1 January	0	9.71	0	0.24	
2 February	0	9.71	0	0.24	
3 March	0	9.71	0	0.24	
4 April	0	9.71	0	0.24	
5 May	0	16.04	9.71	3.33	
6 June	0	16.04	9.71	3.33	
7 July	0	16.04	9.71	3.33	
8 August	0	16.04	9.71	3.33	
9 September	0	16.04	9.71	3.33	
10 October	0	16.04	9.71	3.33	
11 November	0	9.71	0	0.24	
12 December	0	9.71	0	0.24	

**Monthly Demand Rates - Help**  
Unit: [\$/kW]  
Monthly demand rates apply to the maximum monthly utility demand observed within a specific control period.  
These control periods include peak, mid-peak, and off-peak hours, as well as the entire month (non-coincident) and the utility system peak hour (coincident).  
All power demand costs are additive, and allow the definition of complex tariff structures.  
Power demand charges are often a strong driver for the optimization process, leading to a flattened utility demand profile that minimizes power demand costs.

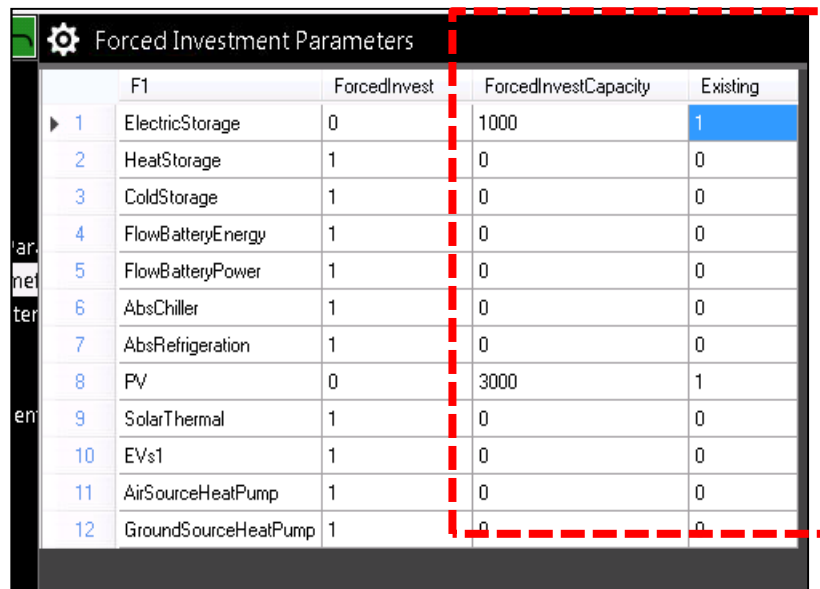
standard window structure: 1: Table navigation ; 2: Data input ; 3: Help

# Building a Model: Reference Case vs. Investment Case

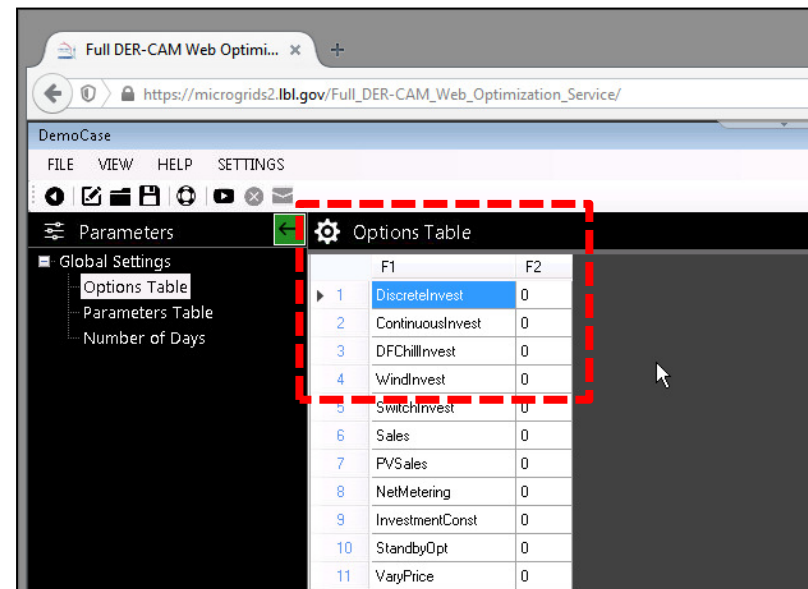
DER-CAM finds the optimal investment solution that satisfies several groups of constrains:

- energy balance (electric, heating, cooling, etc.)
- physical (rated capacity, conversion efficiency, available roof space, etc.)
- economic (discount rate, maximum payback period)

in order to satisfy the economic constrains, a **reference cost** must be obtained and the reference cost can be estimated by running DER-CAM with the existing infrastructure



	F1	ForcedInvest	ForcedInvestCapacity	Existing
1	ElectricStorage	0	1000	1
2	HeatStorage	1	0	0
3	ColdStorage	1	0	0
4	FlowBatteryEnergy	1	0	0
5	FlowBatteryPower	1	0	0
6	AbsChiller	1	0	0
7	AbsRefrigeration	1	0	0
8	PV	0	3000	1
9	SolarThermal	1	0	0
10	EVs1	1	0	0
11	AirSourceHeatPump	1	0	0
12	GroundSourceHeatPump	1	0	0



	F1	F2
1	DiscreteInvest	0
2	ContinuousInvest	0
3	DFChillInvest	0
4	WindInvest	0
5	SwitchInvest	0
6	Sales	0
7	PVSales	0
8	NetMetering	0
9	InvestmentConst	0
10	StandbyOpt	0
11	VaryPrice	0

# Building a Model: Reference Case vs. Investment Case

the total annual energy costs obtained in the reference case will then be used in the investment scenarios to allow estimating savings and return period of new investments

The left screenshot shows the 'Parameters' tab with a red dashed box around the 'Launch Run' button. The right screenshot shows the 'Results' tab with a red dashed box around the 'Results' table. A blue arrow points from the left to the right.

	F1	F2
106	6.3 Detailed Load	
107		
108	+++++ Summary +++++	
109		
110	Total Annual Energy Costs (incl. annualized capital costs and electricity sales)...	234844
111	Total Annual CO2 emissions (kg)	735639

the results obtained in any run are stored on the server and can be sent via e-mail

# Building a Model: Investment Case

after updating the reference costs and CO2 emissions, an investment case can be performed

The first screenshot shows the 'Parameters Table' in the DER-CAM software. The table has two columns, F1 and F2. The 'BaseCaseCost' parameter is highlighted in blue, with a value of 234850. A red dashed box highlights the 'BaseCaseCost' and 'BaseCaseCO2' parameters.

	F1	F2
1	IntRate	0.05
2	Standby	0
3	Controt	0
4	turnvar	0
5	CO2Tax	0
6	macroeff	0.34
7	cooleff	0
8	BaseCaseCost	234850
9	BaseCaseCO2	735639
10	MaxPaybackPeriod	10

The second screenshot shows the 'Options Table' in the DER-CAM software. The table has two columns, F1 and F2. The 'ContinuousInvest' parameter is highlighted in blue, with a value of 1. A red dashed box highlights the 'ContinuousInvest' parameter.

	F1	F2
1	DiscreteInvest	0
2	ContinuousInvest	1
3	DFChillInvest	0
4	WindInvest	0
5	SwitchInvest	0
6	Sales	0
7	PVSales	0
8	NetMetering	0

The third screenshot shows a detailed parameter table with various energy system parameters. The 'Photovoltaic (kW)' parameter is highlighted in blue, with a value of 186. A red dashed box highlights the 'Photovoltaic (kW)' and 'Solar Thermal (kW)' parameters. The 'Stationary Battery' parameter is highlighted in blue, with a value of 98. A red dashed box highlights the 'Stationary Battery' and 'Flow Battery Cap...' parameters. The 'Air Source Heat' parameter is highlighted in blue, with a value of 0. A red dashed box highlights the 'Air Source Heat' parameter. The status bar at the bottom indicates 'The project has been saved 00:00:48'.

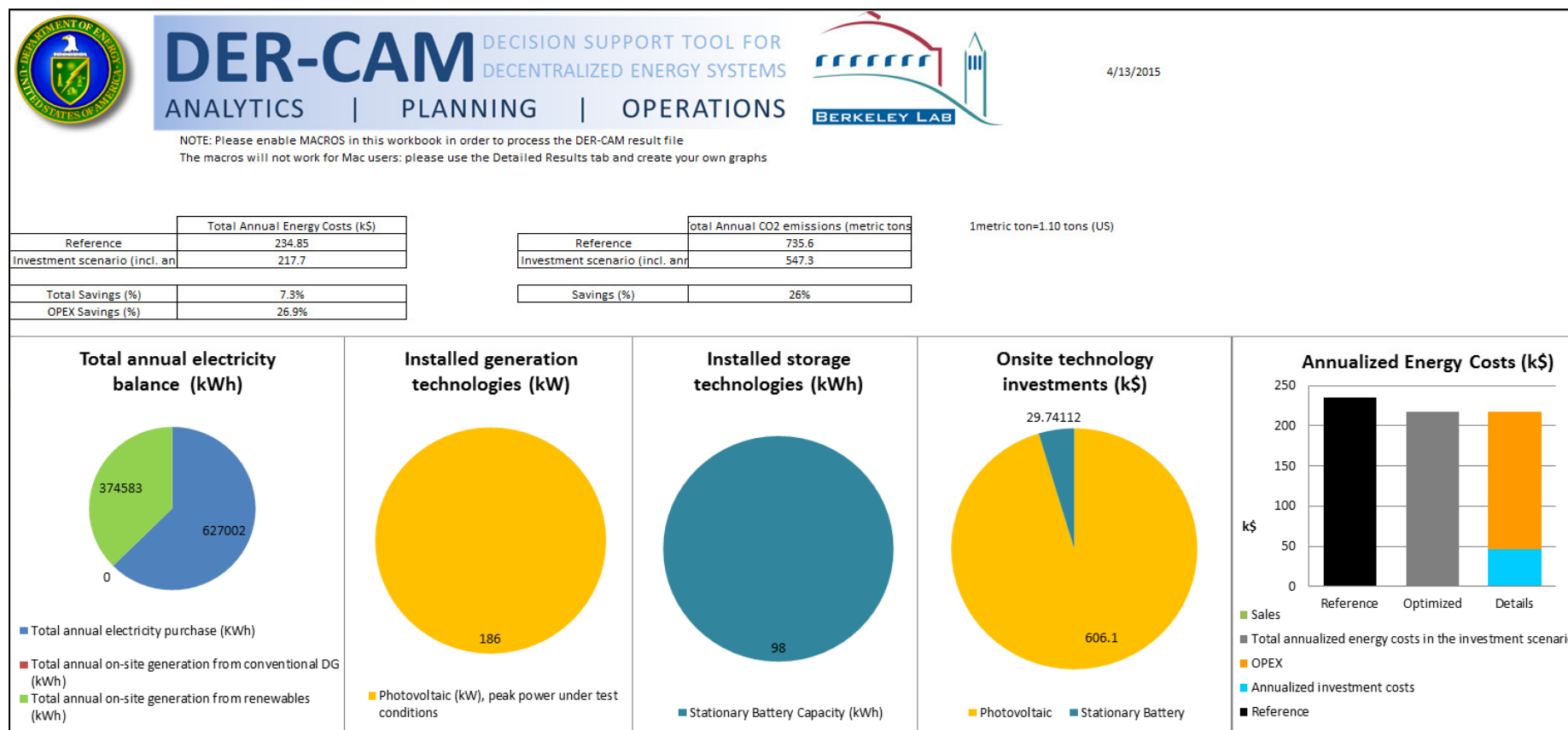
121	+++++++ 1.1.2...				
122					Lifetime
123	Photovoltaic (kW)	186	Size of Photovolt...	1217	30
124	Solar Thermal (kW)	0	Size of Solar The...	0	15
125	Wind power (kW)	0	Installed Capacity...	0	10
126					
127	+++++++ 1.2 Ener...				
128					Lifetime
129	Stationary Battery...	98			
130	Flow Battery Cap...	0			10
131	Flow Battery Pow...	0			10
132	EV Aggregated B...	0			1
133	Heat Storage ca...	0			17
134	Cooling Storage ...	0			17
135					
136	+++++++ 1.3 HVA...				
137	+++++++ 1.3.2...				
138					Lifetime
139	Air Source Heat ...	0			10

The project has been saved 00:00:48



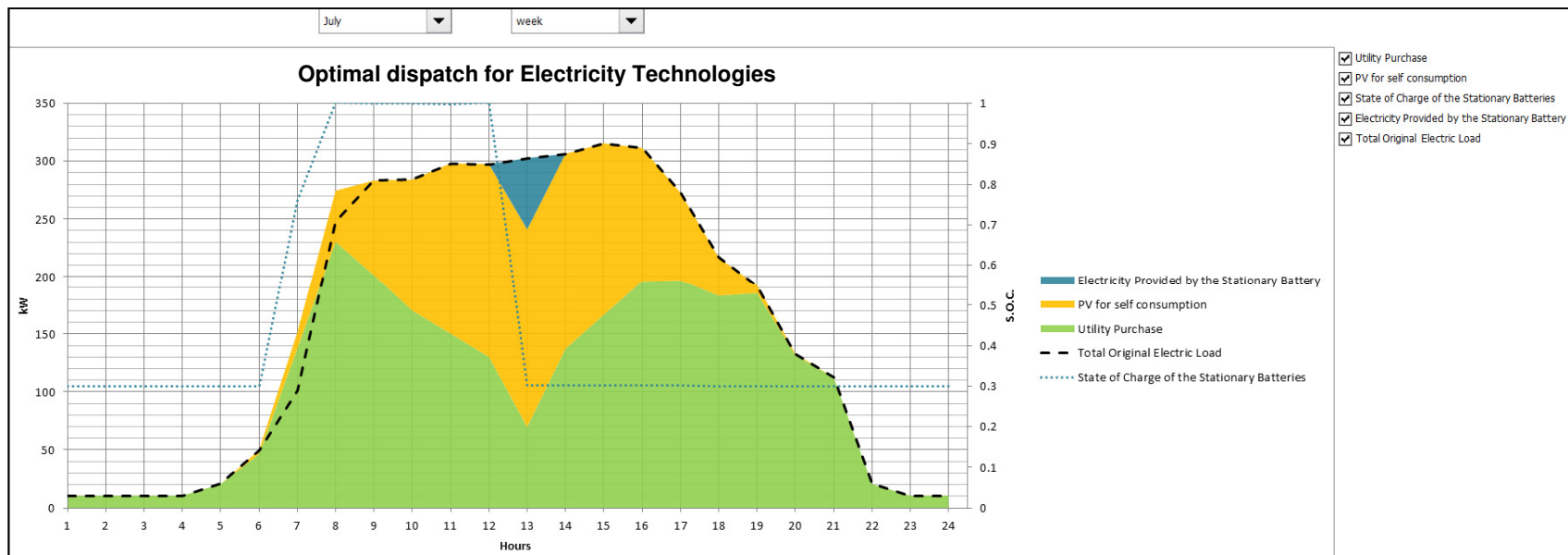
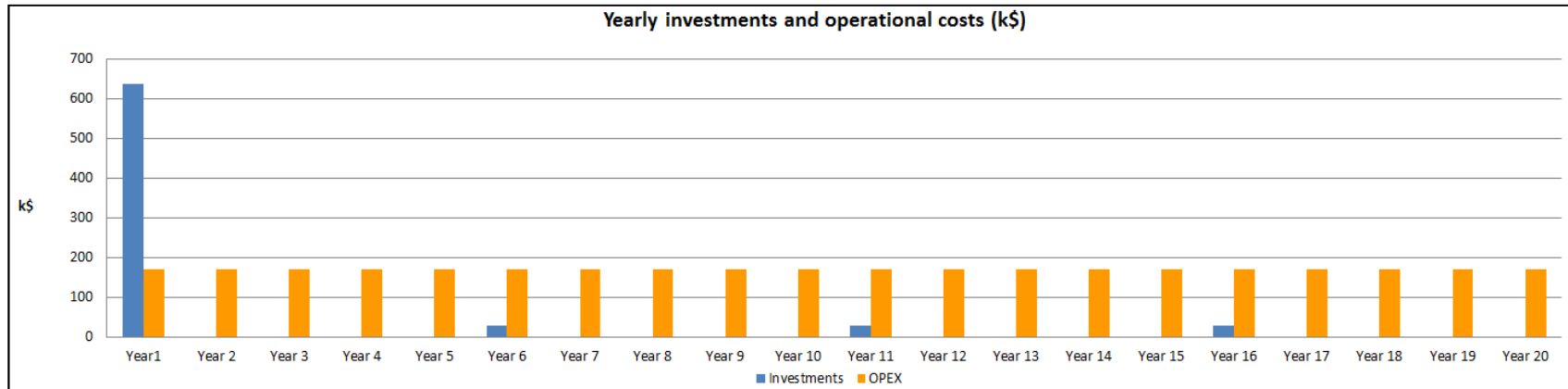
# Building a Model: Results

## Analysis: Economic and Environmental Impact, Savings, Annual Generation Mix



# Building a Model: Results

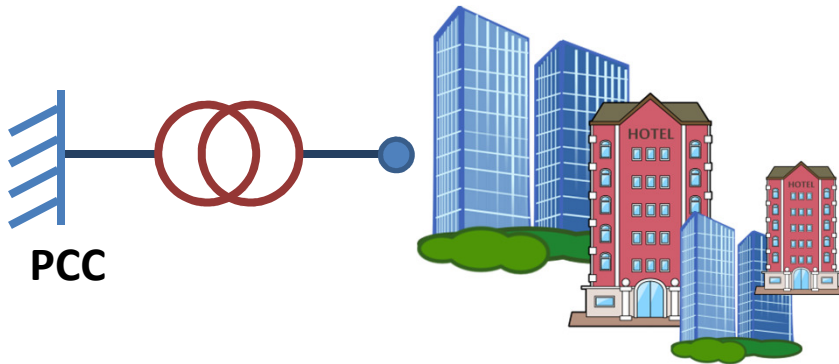
## Analysis: Yearly Investments and Costs, Optimal Generation Mix



*Excerpt of Technical Work Performed in 2<sup>nd</sup> quarter of FY15:*

*Microgrid Topology and Power Flow Analysis*

# Distributed (Multi-Location) vs. Single Site DER-CAM

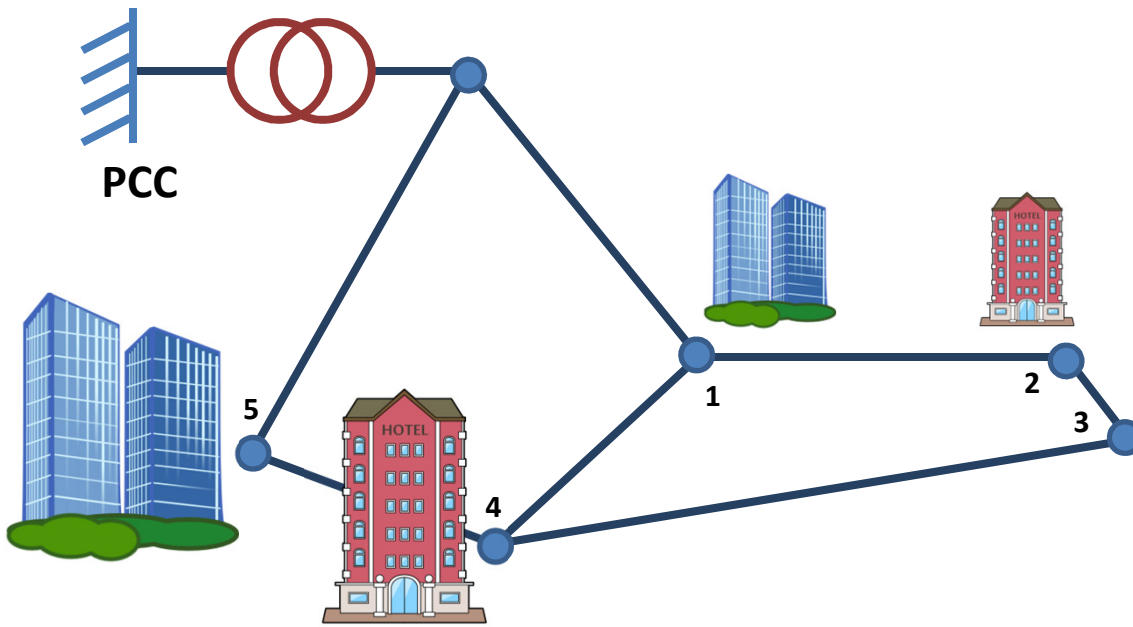


Until now:

- **Input:** load for the entire campus or microgrid
- **Output:** optimal DER type and capacity for the entire campus

New:

- **Input:**
  - load profile for a full year for each location
  - electrical network configuration
- **Output:** optimal DER type and capacity for each location, *considering the network losses, and the network's voltage and current constraints*



# Multi-Location DER-CAM Model Characteristics

- **New:**

the Multi-Location DER-CAM returns the optimum DER portfolio for each bus, considering power flow constraints for each time step (not peak only)

- electrical network configuration (cable impedances and ampacities) is an input
- load profile for each location (bus) is an input
- a linear distribution-level power flow model is integrated into DER-CAM, which considers:
  - cable R, X, and C
  - active and reactive power flow in the network
  - estimates losses in the network
  - imposes constraints on maximum bus voltage, minimum bus voltage, and maximum cable current
- fully functional, but no Graphical User Interface (GUI) at this point
- an interface for the new model is actually the hard part, but needed for wide-spread use

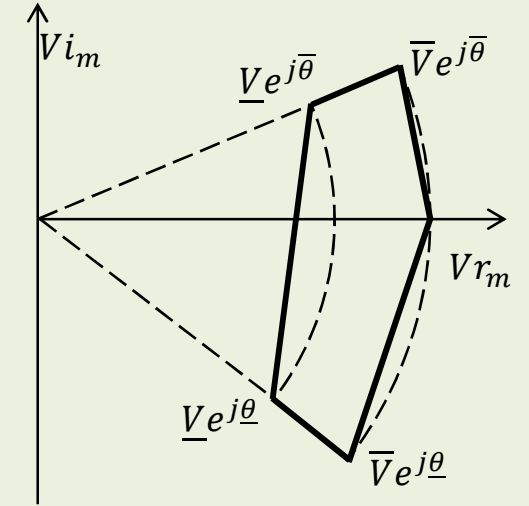
- **Next Step:**

network configuration will also be a decision variable (determined by the optimization)

# Power Flow Model in DER-CAM

$$\begin{aligned}
 Vr_m(t) &= V_0 + \frac{1}{V_0} \sum_{n \neq \text{slack}} (Zr_{m,n}(Pg_n(t) - Pl_n(t)) + Zi_{m,n}(Qg_n(t) - Ql_n(t))) \\
 Vi_m(t) &= \frac{1}{V_0} \sum_{n \neq \text{slack}} (Zi_{m,n}(Pg_n(t) - Pl_n(t)) - Zr_{m,n}(Qg_n(t) - Ql_n(t))) \\
 Ir_{m,n}(t) &= Yr_{m,n}(Vr_n(t) - Vr_m(t)) - Yi_{m,n}(Vi_n(t) - Vi_m(t)) \\
 Ii_{m,n}(t) &= Yi_{m,n}(Vr_n(t) - Vr_m(t)) + Yr_{m,n}(Vi_n(t) - Vi_m(t)) \\
 \sum_m Pg_m(t) &= \sum_m Pl_m(t) + \sum_m \sum_n zr_{m,n} \times I_{m,n}^{sq}(t)
 \end{aligned}$$

**Power Flow Equations [1]**



$$Vi_m(t) \leq \frac{\sin \bar{\theta} - \sin \underline{\theta}}{\cos \bar{\theta} - \cos \underline{\theta}} (Vr_m(t) - \underline{V} \cos \underline{\theta}) + \underline{V} \sin \underline{\theta}$$

$$Vi_m(t) \leq \frac{\sin \bar{\theta}}{\cos \bar{\theta} - 1} (Vr_m(t) - \bar{V})$$

$$Vi_m(t) \leq \frac{-\sin \underline{\theta}}{\cos \underline{\theta} - 1} (Vr_m(t) - \bar{V})$$

$$Vr_m(t) \tan \underline{\theta} \leq Vi_m(t) \leq Vr_m(t) \tan \bar{\theta}$$

**Linearization of Voltage Constraints [2]**

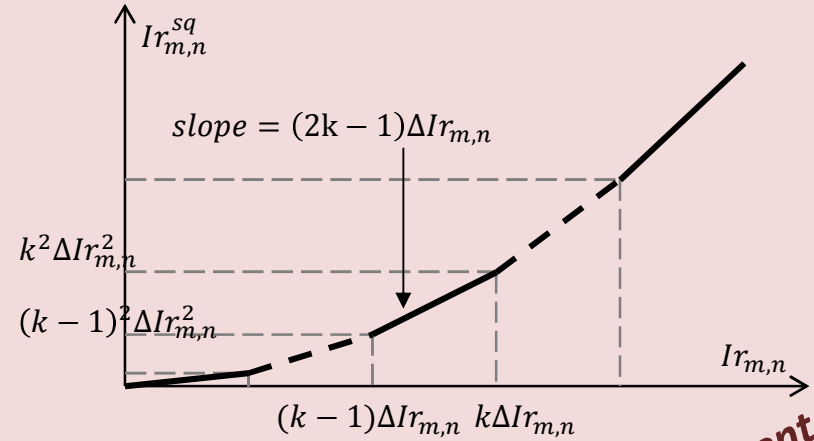
$$Ir_{m,n}^+(t) \geq \pm Ir_{m,n}(t), Ii_{m,n}^+(t) \geq \pm Ii_{m,n}(t)$$

$$Ir_{m,n}^+(t) = \sum_k Ir_{m,n,k}(t), Ii_{m,n}^+(t) = \sum_k Ii_{m,n,k}(t)$$

$$Ir_{m,n,k}(t) \leq \frac{1}{K} \times \bar{Ir}_{m,n}, Ii_{m,n,k}(t) \leq \frac{1}{K} \times \bar{Ii}_{m,n}$$

$$I_{m,n}^{sq}(t) = \sum_k \left( (2k-1) \left( \frac{\bar{Ir}_{m,n}}{K} \right) Ir_{m,n,k}(t) \right) + \sum_k \left( (2k-1) \left( \frac{\bar{Ii}_{m,n}}{K} \right) Ii_{m,n,k}(t) \right)$$

$$Ir_{m,n}^{sq}(t) + Ii_{m,n}^{sq}(t) \leq \bar{I}_{m,n}^2$$



**Linearization of Current Constraints [2]**

[1] Bolognani, S. and S. Zampieri, "On the Existence and Linear Approximation of the Power Flow Solution in Power Distribution Networks," IEEE Transactions on Power Systems, 2015. PP(99): p. 1-10.

[2] Franco, J.F., et al., "A mixed-integer LP model for the reconfiguration of radial electric distribution systems considering distributed generation," Electric Power Systems Research, 2013. 97(0): p. 51-60.

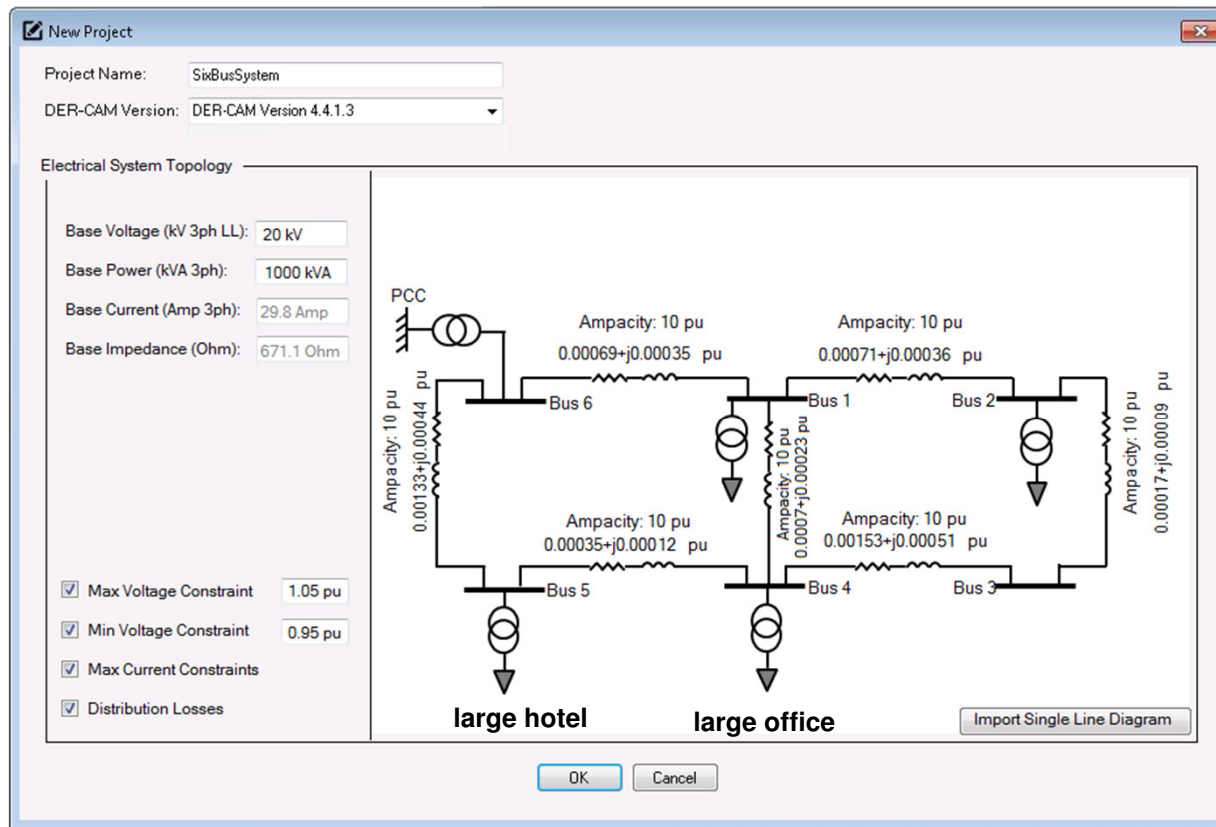
# Case Studies: Comparison between Single Site and Multi-Location DER-CAM

- comparison of Single Site DER-CAM and Multi-Location DER-CAM
- assumptions for a microrgrid with four buildings:
  - small office, maximum electrical load 1,500 kW
  - small hotel, maximum electrical load 2,500 kW
  - large office, maximum electrical load 7,000 kW
  - large hotel, maximum electrical load 6,500 kW
- **Case 1:** Single Site DER-CAM: all loads combined
- **Case 2: Distributed** Multi-Location DER-CAM: electrical network is given and the loads are connected to different buses; a **high ampacity** (10 pu) for the cables
- **Case 3: Distributed** DER-CAM: electrical network is given and loads are connected to different buses; a **low ampacity** (3 pu) for the cables

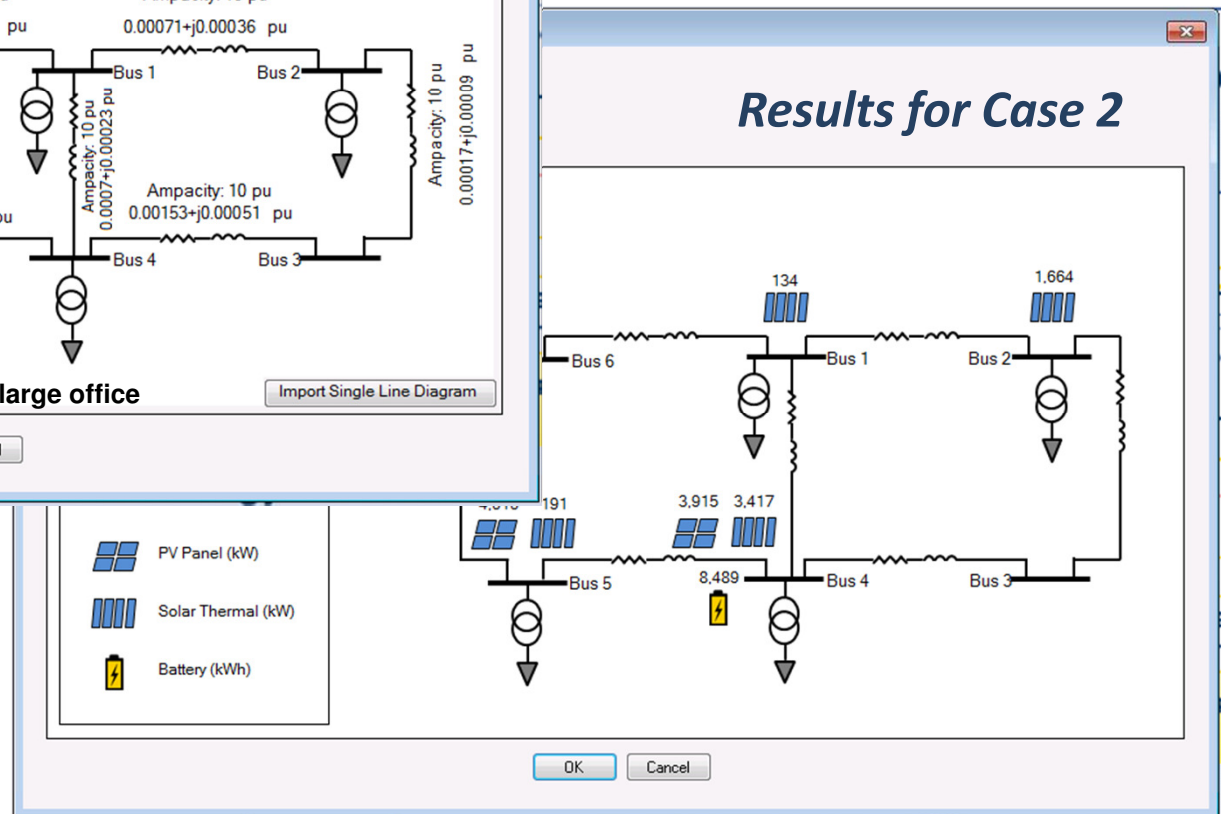


# Multi-Location DER-CAM Interface for Power Flow Models

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this is just an example  
on how it could be  
incorporated in the web  
version



# Summary of the Case Studies

observation:

- the total capacities of each DER type in case 1 (Single Site DER-CAM) and case 2 (distributed with strong network) are very close
- however, the total capacity of each DER type in case 3 (distributed with weak network) is significantly different from cases 1 and 2

DER Type	Battery Capacity (kW)						Photovoltaic Capacity (kW)						Solar Thermal Capacity (kW)					
Location No	1	2	3	4	5	Total	1	2	3	4	5	Total	1	2	3	4	5	Total
Case 1	--	--	--	--	--	<b>7,217</b>	--	--	--	--	--	<b>7,172</b>	--	--	--	--	--	<b>5,590</b>
Case 2				8,489		<b>8,489</b>				3,915	4,010	<b>7,925</b>	134	1,664		3,417	191	<b>5,406</b>
Case 3	18,475	8,656	5,626	10,802	17,385	<b>60,944</b>	4,662	4,654	4,985	4,343	4,985	<b>23,628</b>	134	1,623		3,145		<b>4,901</b>

# DER-CAM

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*Next Steps*

### Outreach and TechTransfer

- continue on successful path for wide acceptance by communities and engineering firms
- training tools for users, workshops, tutorial movies on specific microgrid case problems
- detailed microgrid design for Fort Hunter Liggett

### Technical work

- Microgrid power flow verification with modelling tools such as GridLab-D
- Graphical User Interface for power flow version
- DC power flow?
- networked microgrid optimization (together with ANL)
- enable DER-CAM with unbundled transmission and distribution tariffs for changed tariff structures for advanced microgrids, “adapting to the changing regulatory environments”

# DER-CAM

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Questions and  
comments are very  
welcome!

THANK  
YOU!

Q&A